Fabrication and Characterization of Co-Ni magnetic cantilevers

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Abstract

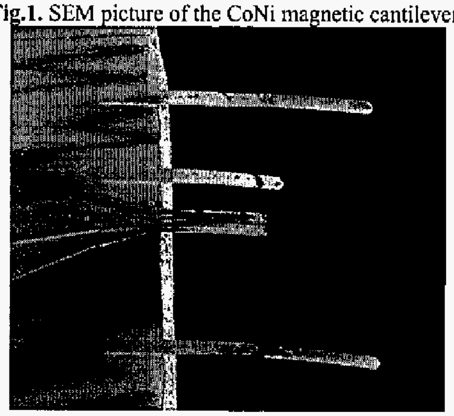
This work is focused on the fabrication of silicon cantilevers coated with magnetic material. An electrodeposited Co-Ni alloy has been used as a magnetic layer. The magnetic and mechanical properties are preliminary evaluated for the design of magnetic devices. The design and fabrication technology of cantilevers coated with Co-Ni films will be presented as an example of a magnetic actuator.

1. Introduction

Magnetic actuation is one of the most suitable working principles for on-liquid environment applications. Cantilevers coated with magnetic materials, as the ones of the MAC mode® AFM, are very promising for bioapplications. Thus, magnetic materials compatible with microelectronic technologies are demanded.

Typically, Ni-Fe permalloys are one of the most employed magnetic materials in Microsystems. However, as it has been demonstrated in our previous works [1, 2], Co-Ni alloys are a good choice due to their high saturation magnetization (1.2 T) and low coercivity (4 $kA{\cdot}m^{-1}$). Moreover, this material can be homogeneously grown by electrodeposition using a simple chloride bath [3, 4] and it is also suitable for a batch fabrication process.

Fig.1. SEM picture of the CoNi magnetic cantilevers



However, if a higher sensitivity is required, cantilevers have to be as thinner as possible, which implies that magnetic layers have to be also the thinner the better, and this way it will be possible to obtain the sensitivity required in some new nanotechnology applications, as can be magnetic resonance force microscopy (MRFM) [5-9]. Therefore, a special effort is necessary in the reduction of the thickness of the seed layer as well as the electrodeposited magnetic layer. Both processes are carefully considered in this work. In addition, the magnetic and mechanical properties of these thin layers are evaluated.

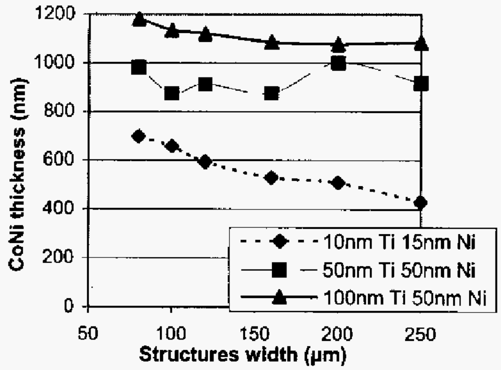
Finally, the design and fabrication technology of cantilevers coated with Co-Ni films are presented as an example of a magnetic actuator (Fig 1).

2. Electrodeposition Process of Co-Ni thin layers

In the electrodeposition process the seed layer is necessary to assure a conductive plating base as well as a good adherence with deposited layer. The influence of the thickness of the seed layer in the deposition rate has been studied. Three different thicknesses of the seed layer were tested: 10 nm Ti and 15 nm Ni, 50 nm Ti and 50 nm Ni and finally, 100 nm and 50 nm Ni. All the deposits were performed on a test chip at the same starting potential (-0.8 V) and deposition time 100 s. The results are presented in *Figure 2*.

With the thinner seed layer (10 nm Ti and 15 nm Ni) low deposition rate has been obtained. Moreover, a strong dependence with the structures dimension has been observed. The deposition rate with the two other layers are similar, so that, as our aim is to reduce the seed layer as much as possible, the best option will be 50 nm Ti and 50 nm Ni.

Fig.2. CoNi thickness depending on the seed layer



The Co-Ni layer is obtained by a chloride bath with boric acid and saccharin. As Co-Ni deposition is an anomalous type, Cobalt (II) concentration was kept in the range of 0.2-0.3 mol·dm^{-3} as a minority metallic ion, whereas Ni (II) was maintained in the range of 0.7-0.9 mol·dm^{-3}. Higher cobalt (II) concentration lead to quasi-pure cobalt deposit. Boric Acid was added to control the pH of the solution and to obtain a best quality deposit. Saccharin was used to decrease the stress of the electrodeposited layer.

The electrodeposition process takes place in a three electrodes cell under potentiostatic conditions (-0.8 V). To minimise hydrogen evolution more negative deposition potentials were avoided as well as a careful control of the pH. The temperature was maintained around 50-60°C to obtain a sufficient deposition rate but with a good appearance of the deposit. After an exhaustive study of the deposits [3], the bath conditions were fixed to achieve an homogeneous, compact and fine-grained 60% Co-40% Ni film. The optimised parameters are shown in *Table 1*.

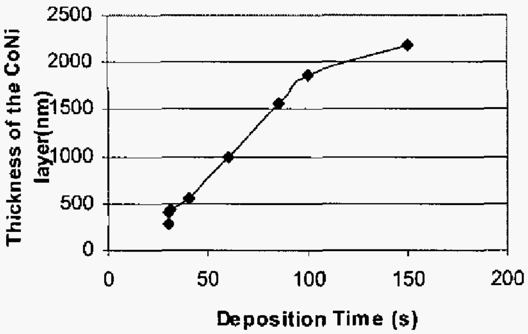
Table1. CoNi bath parameters conditions

Bath Conditions	
Co (II)	0.2-0.3 mol dm^{-3}
Ni (II)	0.7-0.9 mol dm^{-3}
Saccharine	0.5-1.2 g dm^{-3}
Boric Acid	20-40 g dm^{-3}
Reference electrode	Ag// AgCl
pH	3-3.5
Temperature	50-60°C

As thin layers of magnetic deposits are required for the magnetic driven cantilevers, it was necessary to study the process in order to control the deposition time to obtain, in a reproducible way, layers thinner enough for this application. CoNi thickness depending on the deposition time is shown in *Figure 3*.

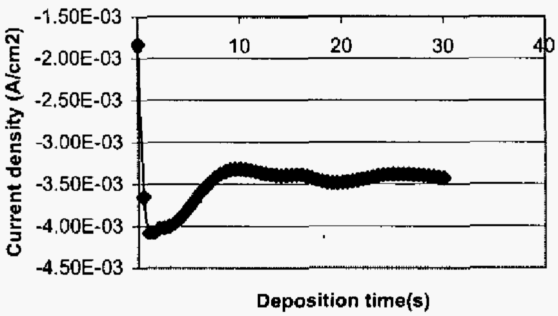
In this figure, we can see how the deposition velocity is not linear, but presents a decrease when deposition times are higher than 100 s, that is, deposition occurs faster at the beginning and it slows later. In our case, times much smaller will be used, being 30 s the minimum time we have been able to achieve a proper electrodeposition with.

Fig.3. CoNi thickness vs. Deposition time



As is shown in *Figure 4* after a stabilisation period of ten seconds the curve arrives to the steady-state current. In this zone of the curve is possible to work with short deposition times to obtain thin Co-Ni layers.

Fig. 4. Current density vs. deposition time

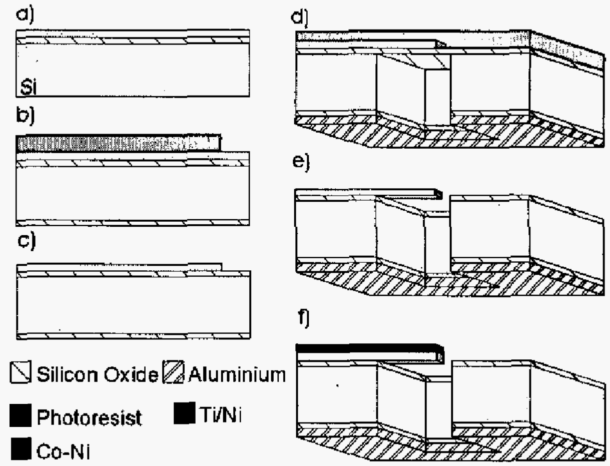


3. Fabrication Process of a magnetic cantilever

A set of masks has been designed to fabricate cantilevers coated by magnetic Co-Ni layers. The technology is based on SOI wafers, Fig. 5.a), where the top silicon layer is used as the structural material. The cantilevers can be fabricated with or without tips, depending on the application they are required for. In this work, the cantilevers were fabricated without tips in order to characterize the fabrication process before including the tips.

The fabrication process of cantilevers without tips begins with a photolithographic step at the front-side, Fig.5.b), followed by a silicon dry etching in order to define the cantilevers, Fig.5.c). Afterwards, an aluminium layer is deposited and patterned by photolithography at the backside of the wafer, Fig.5.d). This layer acts as mask for the DRIE process. This etching stops at the buried silicon oxide layer of the SOI wafer. Next, the buried silicon oxide is removed to release the cantilevers, Fig.5.e). Then, a Ti/Ni layer (50nm Ti and 50nm Ni) is sputtered as a seed layer, and finally the Co-Ni alloy is electrodeposited on the cantilevers, Fig.5.f).

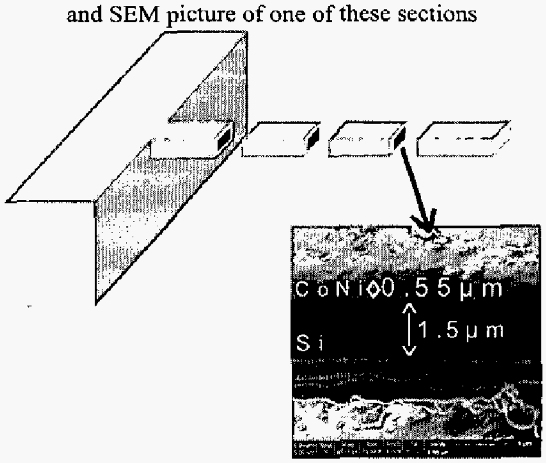
Fig.5. Fabrication process of the CoNi coated cantilevers



4. Characterisation of the magnetic CoNi cantilever

Three sections of the cantilever were performed by FIB in order to check the uniformity along the cantilever. The sections were inspected by SEM and it was observed that the thickness of Co-Ni electrodeposited layer on top keeps constant along the cantilever. A scheme of the three sections of the cantilever is presented in *Figure 6*.

Fig. 6. Scheme of the three sections of the cantilever and SEM picture of one of these sections



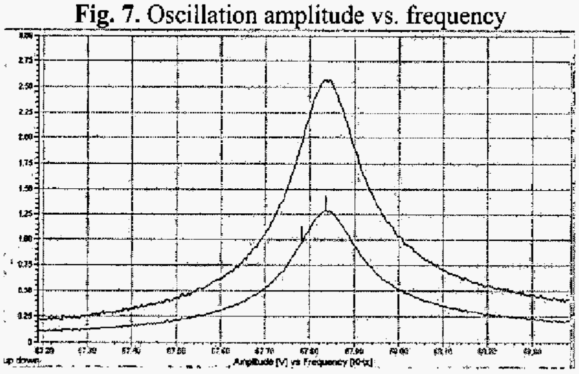
The SEM picture shows the measured thickness of the layer. It is interesting to remark that, although the seed layer was only sputtered on the front side of the cantilever, a non-uniform Co-Ni layer has also grown in the backside.

The roughness of the deposited layer was measured by

AFM obtaining a rms of 17nm.

In addition, we put the cantilevers after having electrodeposited the Co-Ni layer into a Molecular Imaging AFM operating in MAC mode®. This mode differs from usual operating modes because excitation is usually mechanical, making use of a piezoelectric which makes the cantilever, and the whole chip where it is, vibrate. On the other hand, MAC mode® excitation is made using an AC magnetic field, what means that just the cantilever will vibrate. This excitation mode is quite useful when making measurements in liquid environments, for the vibrations in the medium will be greatly diminished.

Fig. 7. Oscillation amplitude vs. frequency



The cantilevers showed an excellent magnetic response to microscope excitation (*Figure 7*) proving that Co-Ni layer could be used to fabricate cantilevers magnetically actives.

The chemical resistance of the magnetic cantilevers have been tested. They show high resistance to alkaline solutions like KOH 40%, TMAH25% at temperatures of 75°C and 80°C respectively. They can also resist more than 4 hours in concentrated fluoride acid. Solvents like acetone, IPA or toluene don't affect the Co-Ni films.

7. Conclusions

Co-Ni electrodeposition process and the seed layer thickness have been optimised to obtain thin layers (down to 400 nm).

The obtained Co-Ni layers show good magnetic, electrical and mechanical properties. They also show high chemical resistance in solvents, alkaline solutions and HF acid.

Furthermore, a new technology has been developed to fabricate Co-Ni magnetic cantilevers that show excellent magnetic response when they are excited by external AC magnetic fields.

In a near future, these cantilevers will be used for bioapplications.

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